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DEPARTMENT OF MINES DEPARTEMENT MYNWESE

GEOLOGICAL SURVEY
GEOLOGIESE OPNAME

TYSONITE FROM MUTUE FIDES

BULLETIN 35

by

J. G. D. Steyn

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CONTENTS

		Page
	ABSTRACT	1
I.	INTRODUCTION	1
II.	SOURCE AND DESCRIPTION OF MATERIAL	6
III.	PHYSICAL AND OPTICAL PROPERTIES	6
IV.	TWINNING	8
V.	DETERMINATION OF UNIT CELL DIMENSIONS	10
VI.	CHEMICAL COMPOSITION	12
VII.	ALTERATION	19
VIII.	MINERALS ASSOCIATED WITH TYSONITE	21
	A. BASTNAESITE	21
	B. FLUORITE	26
	C. HELLANDITE?	27
	ACKNOWLEDGEMENTS	28
	OPSOMMING IN AFRIKAANS	29
	BIBLIOGRAPHY	30

LIST OF ILLUSTRATIONS

TEXT-FIGURES

Figure		Page
1.	Stereographic projection of polysynthetic twins of tysonite	9
2.	Variation in the proportion of CeF_3, LaF_3 and YF_3 in tysonite and fluocerite	17
3.	Variations in the chemical composition of bastnaesite	18

PLATES

Plate

I. Polysynthetic twinning in tysonite from Mutue Fides.

II. Remnants of tysonite in bastnaesite.

III. X-ray diffraction patterns of bastnaesite and an earthy alteration product of tysonite.

IV. Fluorite replacing bastnaesite along basal cleavage planes.

TYSONITE FROM MUTUE FIDES

ABSTRACT

Tysonite from the tin deposits on Mutue Fides 422 has the following optical properties: $n\varepsilon_D = 1.608 \pm .002$; $n\omega_D = 1.614 \pm .002$; $n\omega_D - n\varepsilon_D = .006$; $n\omega_F - n\omega_C = .011$; and S.G. $^{24}_{4} = 5.995 \pm .005$. Microscopically polysynthetic twinning with the first order pyramid $(10\bar{1}2)$ as composition and twinning-plane is prominent, and $0001 \wedge 10\bar{1}2 = 45° 36'$.

X-ray powder diffraction data are given: $a = 4.122 \pm .005$ A, $c = 7.304 \pm .005$ A, $c/a = 1.772$. The mineral alters to bastnaesite and the chemical analysis also suggests partial oxidation. The chemical analysis, specific gravity, refractive indices and X-ray data of the bastnaesite agree with those of this mineral from other localities. Other minerals associated with the tysonite are fluorite, quartz and probably hellandite.

It is also suggested that fluocerite and tysonite are two different minerals, and that the former is an oxidation product of the latter.

I. INTRODUCTION

The fluoride of the rare earth metals, $(Ce,La,Nd)F_3$, an exceedingly rare mineral, was first described by Berzelius in 1818. Originally the mineral was called fluocerite by Haidinger. This mineral was obtained from a pegmatite at Finbo and Broddbo in Dalarne, Sweden, and was subsequently found in the same group of pegmatites at Österby in Dalarne, Sweden (Geijer, 1921, p. 19). A fluoride of Ce, and the La-group from granite pegmatite in the Pike's Peak region in Colorado, was described in 1880 by Allen and Comstock (1880, p. 390) who called it tysonite.

Geijer (1920, p. 9) encountered microscopical grains of fluocerite in the Bastnäs Mine at Riddarhyttan. In a subsequent publication (Geijer, 1921, p. 19) he points out that fluocerite and tysonite are one and the same mineral with the formula (Ce,La,Di)F_3*, and on a basis of priority prefers the name fluocerite.

In 1945 fluocerite was discovered in a pegmatite at Mpuye Hill near Mubende in the Protectorate of Uganda (Roberts, 1945, p. 37 and 1946, p. 31). This mineral was analysed by Bennett who calculated its formula as (Ce,La, Di)$_2O_{0.4}F_{5.2}$ (Roberts, 1946, p. 32).

The present author agrees with Geijer that the fluocerite from Broddbo and the tysonite from Colorado is one and the same mineral species but the study of the data listed in table 1 reveals that the specimens from Österby and Uganda differ from the optically uniaxial negative material from Broddbo and Colorado in being positive and in having a lower specific gravity. Furthermore the material from Colorado is a fluoride with the formula RF_3 (R = rare earth metals) whereas the minerals from Österby and Uganda appear to be oxyfluorides with formulae respectively $R_2O_1F_4$ and $R_2O_{0.4}F_{5.2}$. Owing to an incomplete analysis the exact composition of the Broddbo material (table 1, column 1) is somewhat in doubt but it is at once apparent that the analysis is almost identical to the original analysis of Colorado tysonite (table 1, column 2). Accordingly there is hardly any reason to doubt that the Broddbo material, as indicated by its optical character, is the same mineral species as that from Colorado, namely tysonite.

---

* The symbol Di stands for didymium, a mixture of the two elements neodymium and praseodymium, which was long regarded as one element until Welsbach succeeded in separating out the two components in 1885. Since that time the symbol Di was retained by various authors. In a formula such as this one, it can be understood as the remainder of the La-group.

Table No. 1. Compilation of chemical analyses, and optical and physical properties of tysonite and fluocerite

	1	2	3	4	5
Ce_2O_3	82.64	82.64	42.89	46.03	41.58
La_2C_3 group			39.31	36.00	39.26
Y_2O_3 group	1.12			3.96	0.13
F	(28.05)	(29.98)	28.71	19.49	24.46
CaO			0.18		0.42
CO_2			0.53		0.98
H_2O				1.78	0.71
Rem.			0.41	1.50	3.08
	111.81	112.62	112.03	108.76	110.62
-F=O	11.81	12.62	12.08	8.21	10.30
Totals	100.00	100.00	99.95	100.55	100.32
nω	1.618^{ii}	1.613^{ii}	1.613^{ii}	1.615	1.6185^{iv}
nε	1.611^{ii}	1.607^{ii}	1.607^{ii}		
nω - nε	.007	.006	.006		
nε - nω				$.002^{iii}$	low^{iv}
S.G.	5.93^{i}	6.14^{i}	6.14^{i}	5.7^{iii}	5.8^{iv}
Optical character	–	–	–	+	+

i. Palache, Berman and Frondel (1951, p. 49).

ii. Geijer (1921, pp. 20 and 21).

iii. Hintze (1915, pp. 2567 and 2568).

iv. Roberts (1945, p. 37).

1. Fluocerite (tysonite), Broddbo. Analyst, Berzelius (Geijer, 1921, p.19). Fluorine calculated from R_2O_3+F-(F=O)=100.

2. Tysonite, Colorado, mean of two analyses by Allen and Comstock (Geijer, 1921, p. 19). Fluorine calculated as for 1.

3. Tysonite, Colorado. Analyst, Hillebrand (Hillebrand, 1899, p. 52). Rem. is Fe_2O_3 0.11 and Na_2O 0.30.

4. Fluocerite, Österby. Average of four analyses (Geijer, 1921, p. 19).

5. Fluocerite, Uganda. Analyst, W.H. Bennett. Rem. is ThO_2 1.88, SiO_2 0.12, Al_2O_3 0. 48, Fe_2O_3 0.32, TiO_2 0.01 and MgO 0.27 (Roberts, 1946, p. 32).

It is therefore suggested that the name tysonite should be retained for the uniaxial negative fluoride (Colorado type), and fluocerite applied to the uniaxial positive material which appears to be an oxyfluoride (Österby type). These names are used in this sense in the textbooks on mineralogy which were published prior to Geijer's work (Dana, 1914, pp. 166 and 175; Hintze, 1915, pp. 2559 and 2567) and they are also used in the same sense in this paper.

The mineral from Mutue Fides is regarded as tysonite; its chemical analysis is not convincing but its optical and physical properties, and its X-ray data are in agreement with those of tysonite.

The occurrence of fluocerite (tysonite) in the tinfields of the Potgietersrus District of Transvaal, is known since 1921 as is indicated by a record of a chemical analysis of fluocerite (tysonite) from the Springbok Flats (Hall, 1938, p. 307). The exact source of the analysed sample is not reported but it most probably comes from the Mutue Fides tin-deposits. From this locality the mineral came to the notice of Prof. J. Willemse of the University of Pretoria in 1942. At that time he was doing field-work in that area as a member of the staff of the Union Geological Survey. He submitted the mineral for identification and it was identified as fluocerite in the Union Geological Survey Laboratory by Dr. B. Wasserstein (verbal communication). Subsequently Strauss (1954, pp. 84, 98 and 116) reported this mineral from the Zaaiplaats and Groenvlei tin-mines, some 60 miles north-northeast of Mutue Fides.

The crystal structure of fluorides of the tysonite type was first investigated by Oftedal (1929, p. 272) by means of Laue and powder photographs. He determined the cell constants for tysonite as c=7.280 kX, a=4.112 kX and c/a=1.771, but regards this as a "pseudocell", the "real cell" being a triple hexagonal cell with dimensions c=7.280 kX, a = 7.124 kX, and c/a=1.022. The structure was reinvestigated by Schlyter (1952a, p. 73) in 1952. He found no reflections in Weissenberg rotation photographs that would necessitate a larger cell than Oftedal's "pseudocell." In a parallel study (Schlyter, 1952, p. 61) he shows that tripositive ions of radii close to that of La^{3+}, namely Ce^{3+}, Pr^{3+}, Nd^{3+}, Y^{3+}, etc., gave fluorides of the tysonite type and that the ratio c/a is practically constant (=1.772) for all these fluorides. This ratio is in agreement with the axial ratio a:c = 1:1.7736 which was arrived at by Flink (1910, p. 30) from measurements on tysonite from Broddbo.

The unit cell and orientation of Schlyter is accepted throughout in this study.

II. SOURCE AND DESCRIPTION OF MATERIAL

The sample investigated was kindly contributed by Prof. Willemse of the University of Pretoria. He collected the material from the tin deposits on the farm Mutue Fides 422 in the Potgietersrus District of Transvaal. The farm is situated in the Springbok Flats in a straight line approximately 40 miles southeast of Potgietersrus. The deposits are of hydrothermal origin and occur in, and are related genetically to, granite of the Bushveld Igneous Complex.

The sample, measuring about 2 x 1½ inches, consists of massive tysonite penetrated by veinlets of bastnaesite and fluorite. Microscopically quartz and hellandite? were also observed.

III. PHYSICAL AND OPTICAL PROPERTIES

In hand-specimen the tysonite is dull, yellowish-brown, changing to reddish-brown due to alteration to bastnaesite. In transmitted light it is almost colourless.

Macroscopically cleavage is hardly visible but thin sections show two sets of cleavage: the one parallel to the basal pinacoid (0001) and the other to the first order prism $(10\bar{1}0)$.

No pycnometers of suitable size were available for specific gravity determinations but sufficient accuracy could be obtained by using the apparatus and method described by Hiemstra (1955, p. 276). Air bubbles adhering to the particles were removed by heating the container with the particles and about $\frac{3}{4}$ of its volume of water under diminished pressure. A close check was kept on the temperature of the distilled water during the determination, and the results were corrected for the density of pure water at 4°C.

The average of three determinations on different portions of material is S.G. $^{24}_{4}$ = 5.943 ± .005. This value is in agreement with that of the Broddbo material (table 2) but, owing to the partial alteration to bastnaesite and probably also to an oxide or oxyfluoride, certainly does not represent the true specific gravity of the tysonite. From a thin section of material similar in colour to that used for specific gravity determination, the amount of alteration product was roughly estimated at 5 per cent by volume. The corrected value for tysonite is S.G. $^{24}_{4}$ = 5.995 ± .005, assuming the specific gravity of the alteration product to be 4.97 (S.G. of bastnaesite).

Table No. 2. – Physical and optical properties of tysonite

	Mutue Fides	Colorado	Broddbo
S.G.	5.995 ± .005	6.14[i]	5.93[i]
$n\varepsilon_D$	1.608 ± .002	1.607[ii]	1.611[iii]
$n\omega_D$	1.614 ± .002	1.613[ii]	1.618[iii]
$n\omega_D - n\varepsilon_D$	.006	.006	.007
$n\omega_F - n\omega_C$	.011		

i. Palache, Berman and Frondel (1951, p. 49).

ii. As quoted by Geijer (1921, p. 21). Sodium light.

iii. Geijer (1921, p. 20). Sodium light.

The mineral is uniaxial negative. Its refractive indices were determined according to a single variation method at room temperature (23°C). The indices were matched in monochromatic light with those of immersion liquids. For the determination of $n\varepsilon$ the grains were brought to the desired orientation on a universal stage. The results obtained are listed in table 2.

IV. TWINNING

The latest textbooks on mineralogy (Winchell, 1951, p. 31 and Palache, Berman and Frondel, 1951, p. 48) do not report any evidence on twinning in fluocerite (tysonite). Koechlin, however, reports "Schalenbildung" on the first order pyramid in tysonite from Pike's Peak, Colorado (Hintze, 1915, p. 2561) and Weibull polysynthetic twinning in fluocerite from Österby (Hintze, 1915, p. 2568). Polysynthetic twinning is common in the Mutue Fides mineral (see plate I). A study of thin sections on the Fedorow Universal Stage reveals the following (see fig. 1):

a. The composition-plane occurs in the same zone as the basal pinacoid (i.e. ε direction) and the first order prism $(10\bar{1}0)$. Accordingly the composition-plane corresponds to a pyramid of the first order.

b. The interfacial angle between (0001) and the composition-plane is 46°. This value is the average of a series of determinations some of which were carried

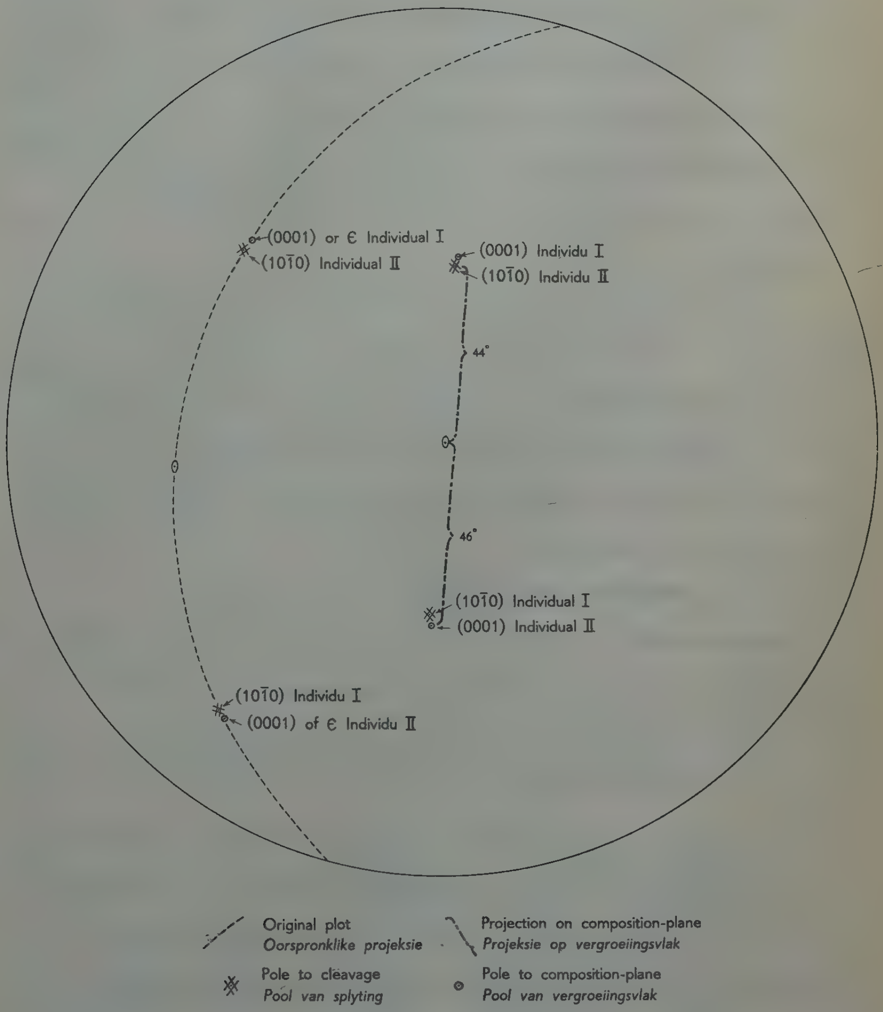

(0001) or ∈ Individual I
(10$\bar{1}$0) Individual II
(0001) Individu I
(10$\bar{1}$0) Individu II
44°
46°
(10$\bar{1}$0) Individual I
(0001) Individual II
(10$\bar{1}$0) Individu I
(0001) of ∈ Individu II
Original plot
Oorspronklike projeksie
Projection on composition-plane
Projeksie op vergroeiingsvlak
Pole to cleavage
Pool van splyting
Pole to composition-plane
Pool van vergroeiingsvlak

Fig. 1.—Stereographic projection of polysynthetic twins of tysonite.

out with a set of Fedorow hemispheres having a refractive index ($n = 1.648$) above those of the mineral, and others with hemispheres having a refractive index ($n = 1.554$) below those of the mineral. The variation of the measured interfacial angle due to the different hemispheres used is within the limits of experimental error, and the value of 46° is considered to be correct to ± 1°.

From figure 1 it is also obvious that two adjacent lamellae can be brought into similar orientation by revolving the one through 180° about the pole to the composition-plane. Consequently the pole to the composition-plane and the twinning-axis coincide making the composition-plane also the twinning-plane. The Miller indices of the twinning-plane, determined according to the equation: $\tan (0001 \wedge h0\bar{h}l) \times \frac{1}{2}\sqrt{3} = h/l \times c$ (Ford, 1932, p. 132), are $(10\bar{1}2)$. The true interfacial angle would be 45°39'.

V. DETERMINATION OF UNIT CELL DIMENSIONS

The X-ray examination of the tysonite was carried out on a Seifert X-ray unit. Powder diffraction photographs were taken with cameras of the Debye-Scherrer type in which the films are mounted according to the method of Straumanis (1949). Unfiltered cobalt-radiation produced at 32 kV. and 10 mA. was used. The method described by Wasserstein (1951,p.106) was adopted for film measurement and shrinkage correction.

The values of θ as listed in table 3 are the average from two photographs. These values were converted to interplanar spacings by using suitable tables. The hkl for each reflection was derived from the indexed $\text{Sin}^2\theta$ values for (i), tysonite from W. Cheyenne Canon, Colorado (Oftedal, 1929, p. 273) and (ii), artificial LaF_3 (Schlyter, 1952a, p.74). Both, Schlyter and Oftedal, used copper-radiation and it was therefore necessary to convert their diffraction angles into interplanar spacings so as to enable comparison with the Mutue Fides tysonite. The cell dimensions listed in table 3 were determined from the higher θ values and were corrected for absorption by the extrapolation method according to which the calculated cell dimensions are plotted against $\frac{1}{2}(\text{Cos}^2\theta/\text{Sin}\ \theta.\text{Cos}^2\theta/\theta)$. The unit-cell determinations were facilitated by the fact that the ratio c/a is practically constant (1.772) for fluorides of the tysonite type (Schlyter, 1952, p. 63).

Table No. 3. - X-ray data of tysonite

	1			2		
hkl	Int.(est.)	θ Co rad.	d A.	Int.	θ Cu rad.	d A.
101	8	16.34	3.19	s	13.96	3.19
102	½	20.97	2.50	-	-	-
103β	1	23.48		w	20.32	
110	5	25.99	2.04	m	22.01	2.06
103	10	26.55	2.00	s	22.61	2.00
112, 200	5	30.14	1.78	m	25.64	1.78
201	5	31.27	1.73	m	26.43	1.73
203	4	38.60	1.43	s	32.60	1.51
114	3	41.04	1.38	m	34.48	1.36
105	3	41.59	1.35	m+	34.93	1.35
211	2	42.54	1.32	s	35.73	1.32
213β	3	42.70		vw	36.52	

Table No. 3. (Cont.)

	1			2		
hkl	Int.(est.)	θ Co rad.	d A	Int.	θ Cu rad.	d A.
006	-	-	-	vw	39.50	1.21
213	7	49.50	1.177	s	41.04	1.173
106	1	51.21	1.164	w	42.14	1.148
205	7	52.39	1.129	s	43.13	1.127
214	1	55.86	1.08	-	-	-
116	6	58.81	1.046	m+	47.5	1.045
220	1	60.30	1.030	w	48.65	1.026
215 310 222	7	64.77	0.989	s	51.28	0.987
311	6	65.85	0.980	m+	52.03	0.977
313	4	77.29	0.917	-	-	-
216	1	77.84	0.915	-	-	-
203	2	81.76	0.904	-	-	-
a	4.122 ± .005 A			4.120 ± .003 A		
c	7.304 ± .005 A			7.295 ± .007 A		
c/a	1.772			1.771		

1. Tysonite from Mutue Fides. Co radiation. Camera rad. = 114.59 mm.

2. Tysonite from W. Cheyenne Canon, Pike's Peak, Colorado. Cu radiation. Camera radius 57.65 mm. (Oftedal, 1929, p. 273) Cell dimensions (Oftedal's "pseudocell") from precision measurements on p. 276. These values have been corrected for wavelengths.

VI. CHEMICAL COMPOSITION

In contrast to the optical properties of the Mutue Fides mineral the analysis in table 4 column 1 is not in exact agreement with that of tysonite from Colorado and

Broddbo (table 1, analyses 1, 2 and 3). It differs in having approximately 2.5 per cent. less fluorine and correspondingly more rare earths oxide. Accordingly the analysis corresponds to the formula $R_2O_{0.4}F_{5.2}$ which is in exact agreement with the formula suggested by Bennett for the fluocerite from Uganda. It thus appears that there is chemically no difference between the optically uniaxial negative mineral from Mutue Fides and the uniaxial positive mineral from Uganda. This is apparent rather than real.

The degree of alteration of the Uganda mineral is not given in the literature but the Mutue Fides mineral is partially altered to bastnaesite, the fluocarbonate of the rare earths, and an earthy product. These alteration products made it impossible to obtain pure tysonite, and the material that was analysed contained at least 5 per cent. of this impurity. This conclusion is based on a study of thin sections of material similar to that analysed.

Table No. 4. - Chemical analyses of tysonite from Mutue Fides

	1	2	3
Ce_2O_3	36.31	32.50	35.80
La_2O_3 group	47.50	31.29	34.46
Y_2O_3 group	1.12	12.0	13.22
CaO	nil	6.18	
Fe_2O_3		1.05	1.16
Al_2O_3		0.55	0.61
TiO_2		1.20	1.32
SiO_2		0.33	0.36
CO_2	trace		

Table No. 4. (Cont.)

	1	2	3
F	26.00	24.66	22.55
	110.93	109.76	109.48
-F=O	10.93	10.36	9.48
Totals	100.00	99.40	100.00

Analysis 1 = 87 $(Ce_{0.42}La_{0.56}Y_{0.02})F_3$ (tysonite) +
13 $(Ce_{0.42}La_{0.56}Y_{0.02})_2O_3$

1. Tysonite (partially altered), Mutue Fides 422, Potgietersrus District, Transvaal. Analyst, Abraham Kruger, Division of Chemical Services, Pretoria. HCl used for CO_2 determination. For the interpretation the following atomic weights were used: Ce = 140.13, La = 138.92, Y = 88.92.

2. Fluocerite (tysonite) and fluorite intergrowth from the Springbok Flats, Transvaal. Analysed in 1921 (Hall, 1938, p. 307).

3. Analysis 2 after correcting for fluorite and recalculated to 100.

The analysis listed in table 4 is, therefore, not regarded as being the true composition of the tysonite which is believed to correspond to the formula RF_3.

In the analysis, only traces of CO_2 are recorded meaning that only a portion of the alteration product can be bastnaesite. The analyst agreed that the CO_2 content could be as much as 0.5 per cent.which is approximately equivalent to 2.5 per cent. bastnaesite. This leads to the conclusion that the earthy material is probably an oxyfluoride or oxide of the rare earth matals involved (see discussion on the alteration).

The uncertain nature of the earthy alteration product made it impossible to calculate the true composition of the tysonite.

The analysis that was carried out in 1921 on an intergrowth of fluocerite (tysonite) and fluorite from the Springbok Flats in Transvaal is listed in column 2 of table 4. The exact locality of the material submitted for this analysis is unfortunately not known but it is fairly certain that the mineral came from Mutue Fides; this deposit is situated in the Springbok Flats and is the only deposit in that area in which tysonite is known to occur. Moreover a geological report on the Mutue Fides deposits was published in 1921 suggesting that a geological investigation of the deposits was carried out at about the same time as this analysis was made.

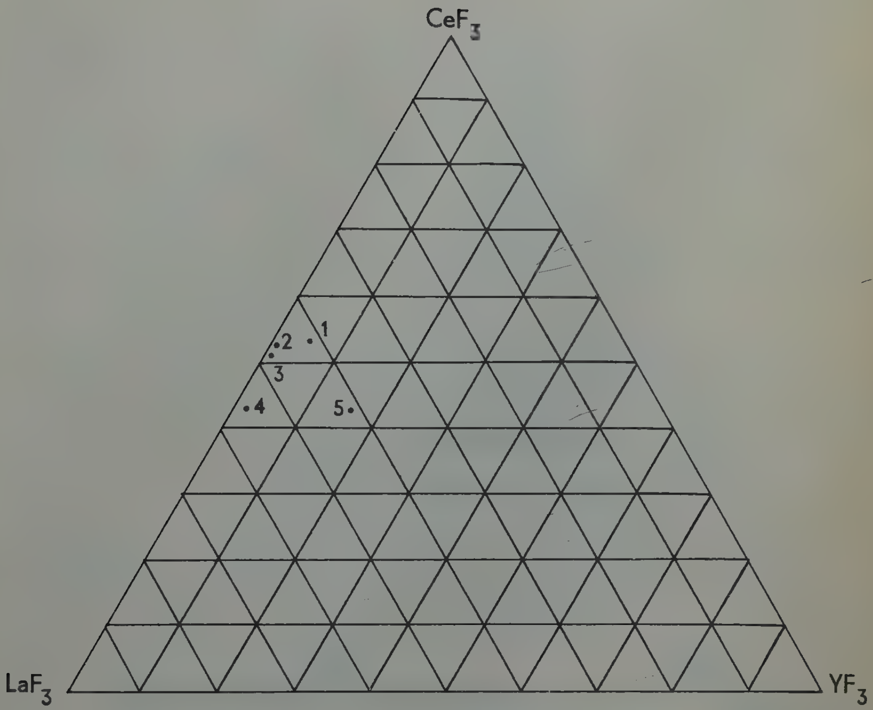
This analysis, after being corrected for fluorite and neglecting the small amounts of Al_2O_3, TiO_2, Fe_2O_3 and SiO_2, reflects less fluorine than the new analysis of the Mutue Fides material and corresponds to the formula $R_2O_{0.8}F_{4.4}$. The deficiency of fluorine in the corrected analysis can be due to the fact that in making the correction for fluorite impurities, all the CaO was relegated to fluorite (CaF_2) whereas part of it, and even a part of the rare earth metals, may be derived, as the Al_2O_3, TiO_2, etc, from other mineral impurities, such as titano-silicates of Ca and the rare earths. On the other hand it can be an analysis of a true oxyfluoride from another locality than Mutue Fides, or it is also possible that both, the oxyfluoride and the fluoride, occur in the same deposit, the former being an oxidation product of the latter.

A further point of interest in the 1921 analysis is the high percentage of Y_2O_3 (12.0 per cent). This oxide is not reported in the analysis of tysonite from Colorado. That from Broddbo and Mutue Fides contains 1.12 per cent. Y_2O_3, the fluocerite from Österby 3.96 per cent. and that from Uganda 0.13 per cent.

For comparative purposes the various chemical analyses of fluocerite and tysonite were recalculated in terms of CeF_3, LaF_3 and YF_3. The results are given diagrammatically in figure 2. It is obvious that the relative proportions of CeF_3, LaF_3 and YF_3 are approximately the same in the tysonite from Colorado and the fluocerite from Uganda (analyses 2 and 3 in figure 2). The Österby mineral (analysis 1) has a CeF_3 content more or less similar to that of the minerals from Uganda and Colorado but a lower LaF_3 and correspondingly a higher YF_3 content. The CeF_3 content of the Mutue Fides and the Springbok Flats material (analyses 4 and 5) is almost identical but is much lower than that of the Colorado, Uganda and Österby material, and $LaF_3 + YF_3$ correspondingly higher.

The cerium content is thus also in favour of the suggestion that the Springbok Flats mineral was collected at Mutue Fides, but its high percentage of yttrium suggests the opposite. The determination of Y_2O_3, however, involves a series of precipitations to separate the yttrium earths from the lanthanum earths, and the author is of opinion that the abnormal Y_2O_3 content of the Springbok Flats mineral is due to an incomplete separation of Y_2O_3 and La_2O_3.

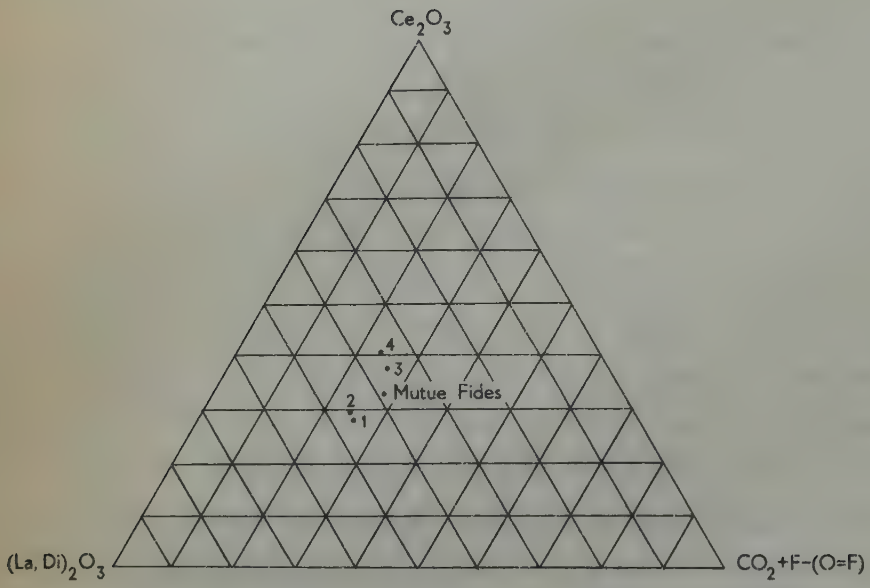
The substitution of one tripositive rare earth ion by another is also prominent in the analyses of bastnaesite (see figure 3), and the fact that the optical and physical properties of the minerals concerned are not affected



1. Fluocerite, Österby	(analysis 4 in table 1)
2 Tysonite, Colorado	(" 3 " " 1)
3. Fluocerite, Uganda	(" 5 " " 1)
4. Tysonite, Mutue Fides	(" 1 " " 4)
5. Fluocerite?, Springbok Flats	(" 3 " " 4)

1. Fluoseriet, Österby	(analise 4 in tabel 1)
2. Tisoniet, Colorado	(" 3 " 1)
3. Fluoseriet, Uganda	(" 5 " 1)
4. Tisoniet, Mutue Fides	(" 1 " 4)
5. Fluoseriet?, Springbokvlakte	(" 3 " 4)

Fig. 2.—Variation in the proportion of CeF_3, LaF_3 and YF_3 in tysonite and fluocerite.



No	Locality	Reference
1.	Bastnäs, Sweden	Glass and Smalley (1945, p. 611 analysis 2)
2.	Bastnäs, Sweden	" " " (" " " 3)
3.	Cheyenne Mt., Pike's Peak, Colorado	" " " (" " " 5)
4.	Ambositra, Madagascar	" " " (" " " 6)

Nr	Vindplek	Verwysing
1.	Bastnäs, Swede	Glass and Smalley (1945, p. 611, analise 2)
2.	Bastnäs, Swede	" " " (" " " 3)
3.	Cheyenne Mt., Pike's Peak, Colorado	" " " (" " " 5)
4.	Ambositra, Madagaskar	" " " (" " " 6)

Fig. 3.—Variations in the chemical composition of bastnaesite.

markedly is explained by the close similarity in the ionic radii of the tripositive rare earth ions (Ce^{3+} = 1.18kX, La^{3+} = 1.22kX, and Y^{3+} = 1.06kX). Furthermore the atomic weight of La (138.92) and Ce (140.13) is very much the same. That of Y (88.92) is much lower but the only mineral of the group under discussion in which this element appears to be present in quantity, is one of which the optical properties are not known, viz. the mineral from the Springbok Flats (1921 analysis).

Schlyter (1952, p. 61) shows experimentally that a complete range can exist from CeF_3 to LaF_3 without a change in the crystal structure, and that Y^{3+} can replace La^{3+} up to Y/Y ± La = 0.65, also without a change in the crystal structure.

VII. ALTERATION

The characteristic replacement of tysonite by bastnaesite and an opaque earthy product is visible in every thin section of the Mutue Fides mineral. Even portions that macroscopically appear unaltered are microscopically seen to be altered. The replacement often proceeds along cleavage cracks and twinning-planes and in an advanced stage of alteration the tysonite occurs as islands in bastnaesite (plate II).

The optical orientation of the bastnaesite replacing the tysonite is usually, but not always, identical to that of the host mineral. In some sections bastnaesite cuts across the twinning lamellae of tysonite without being influenced by the twinning. In such cases the optical orientation of the bastnaesite corresponds to that of one set of lamellae.

These optically orientated pseudomorphs of bastnaesite after tysonite have been described by Oftedal (1931, p. 466) who attributes the phenomenon to a similarity in the crystal structure of the two minerals.

Hidden suggests that the earthy product contains some lanthanite, $(La,Ce)_2(CO_3)_3.8H_2O$, and Geijer that it is a hydrate of cerium (Geijer, 1921, p. 21). Some of this earthy matter in the material from Mutue Fides was removed from thin sections for an X-ray examination. It produced a weaker but exactly similar pattern to that of bastnaesite, without any additional reflection (plate III). This weaker pattern may indicate a lower crystallinity for the earthy material and it can thus be argued that the material is bastnaesite in a metamict state but Geiger counter tests and autoradiographs prove that radio-active material is absent in the sample investigated. Furthermore, the sample submitted for a chemical analysis contained at least 5 per cent. alteration products but the analysis indicates only traces of CO_2 meaning that only a portion of the alteration product is in fact bastnaesite. This leads to the conclusion that the earthy product consists of bastnaesite, which is responsible for the X-ray pattern, and an oxide or oxyfluoride of the rare earth metals, and that this oxidised material does not yield X-ray diffraction lines owing to it being in a cryptocrystalline or even amorphous state.

In thin sections of the most altered portions of the sample investigated, clear colourless bastnaesite is seen to be the principal alteration product whereas the earthy matter predominates in the least altered portions. Furthermore, it was noticed that the earthy material occurs along the contact between bastnaesite and tysonite. This led the author to the conclusion that the earthy matter is in an intermediate state between tysonite and bastnaesite suggesting that the former is first oxidised and thereafter carbonatised.

The alteration of tysonite is due to the higher affinity of fluorine for calcium than for the rare earth metals, and the formation of bastnaesite is probably brought about by a reaction between tysonite and hydrothermal solutions rich in CO_2, CaO, etc. Accordingly the oxidation of tysonite into fluocerite may result if there is a deficiency of CO_2 and an excess of oxygen. The oxyfluorides from Uganda and Österby are possibly products of oxidation.

VIII. MINERALS ASSOCIATED WITH TYSONITE

A. BASTNAESITE

In hand-specimen the bastnaesite occurs as veinlets penetrating the tysonite. The colour of this mineral is brown and its lustre greasy. It exhibits a perfect parting on (0001). The lustre on the parting-plane is pearly.

Under the microscope it is seen to replace tysonite (plate II), the two minerals being optically orientated in parallel position. The largest grains of the bastnaesite are often composed of slightly diverging basal cleavage plates, a phenomenon also noticed by Geijer (1920, p. 11) in bastnaesite from Bastnäs.

The optical and physical properties of the bastnaesite from Mutue Fides agree closely with those of bastnaesite from other localities (table 5) and its X-ray diffraction spacings are almost in exact agreement with those of bastnaesite from W. Cheyenne Canon, Pike's Peak, Colorado (table 6).

Table No. 5. - Optical and physical properties of bastnaesite from Mutue Fides and other localities

	1	2	3	4	5
$n\omega$	1.717	1.716	1.717	1.718	1.716
$n\varepsilon$	1.818	1.817	1.818	1.819	1.816
$n\varepsilon - n\omega$	.101	.101	.101	.101	.100
S.G.	5.12-5.20		4.948	4.99	4.965±.005

	Locality.	Reference.
1.	Pike's Peak, Colorado.	Glass and Smalley (1945).
2.	Jamestown, Colorado.	Glass and Smalley (1945).
3.	Madagascar.	Glass and Smalley (1945).
4.	Gallinas Mts., New Mexico.	Glass and Smalley (1945).

5. Mutue Fides. Refractive indices for Na light at 23°C. For the determination of the specific gravity the same method and apparatus as for the determination of the specific gravity of tysonite were used.

Table No. 6. - X-ray powder diffraction spacings of bastnaesite

1		2	
Int. (est.)	d A	Int.	d A
1	4.73	-	-
8	3.49	6	3.54
9	2.83	9	2.85
½	2.41	2n	2.39
8	2.04	9	2.04
5	2.00	8	2.00
8	1.88	9	1.88
3	1.77	7n	1.76
7	1.66	9	1.66
4	1.56	7	1.56
3	1.47	7	1.47
5	1.43	8	1.44
5	1.34	6	1.34
10	1.30	10	1.29
4	1.28	7	1.27
8	1.178	7n	1.19
-	-	7b	1.17
8	1.153	7	1.15
7	1.067		
7	1.038		
8	1.007		
6	0.988		
8	0.968		
5	0.960		
6	0.947		
7	0.917		

1. Bastnaesite from Mutue Fides. Co radiation.
2. Bastnaesite from W. Cheyenne Canon, Colorado. Cu radiation. Oftedal (1930, pp. 240 and 241). A.S.T.M. cards No. 2-4010.

The chemical analysis of this mineral is listed in table 7. A spectrographic analysis on a portion of the material that was submitted for the chemical analysis, shows, in addition to the elements determined chemically, some Ca and traces of Ge, Mg, Si, and Fe. The remains of 4.91 per cent.(table 7, column 1) are, therefore, considered to be mainly CaO derived from fluorite impurities in the bastnaesite. Relegating the CaO to fluorite the sample analysed had the following mineral composition:

Bastnaesite	93.16%
Fluorite	6.84%

The composition of the bastnaesite after deducting for fluorite and recalculating to 100, is shown in column 2 of table 7.

From the work of Glass and Smalley (1945) on bastnaesite it follows that in various chemical analyses of this mineral "The combined percentages of the cerium groups, where the greatest difference might occur, vary from 73.59% to 76.80%, with a difference of 3.21%; CO_2 from 19.11% to 20.20%, with a difference of 1.09%; and F from 5.23% to 7.83%, with a difference of 2.60%" (p. 612). In the analyses compiled by Glass and Smalley the ratio $Ce_2O_3/(La,Di)_2O_3$ varies from 0.622 to 1.116 (fig. 3).

The fluorine content and the ratio $Ce_2O_3/(La,Di)_2O_3$ of the Mutue Fides mineral fall within the limits of variation given by Glass and Smalley but the CO_2 content is 3.4% higher than the highest value given by them for CO_2

and the total percentage of rare earths correspondingly lower. The most probable explanation for this high CO_2 content is that the loss on ignition (method used for CO_2 determination) consisted of CO_2 and some fluorine. The remains of 4.91% should, therefore, in fact be higher in the original analysis (table 7, column 1) thus indicating a higher percentage of fluorite impurities in the analysed sample and accordingly a higher percentage of rare earths in the recalculated analysis of the bastnaesite (table 7, column 2). Another explanation is that the bastnaesite of Mutue Fides might be accompanied by small quantities of synchisite, $(Ce,La)(CO_3)F.CaCO_3$, or parisite, $2(Ce,La)(CO_3)F.CaCO_3$. This could not be confirmed by a study of thin sections because the colour and birefringence of these three minerals (bastnaesite, synchisite, and parisite) are so similar that synchisite and parasite can easily be overlooked when present in small quantities in bastnaesite.

Parisite has been identified by Söhnge (1945, p. 176) in the tin-deposits of Zaaiplaats which are genetically related to those of Mutue Fides. According to Palache, Berman, and Frondel (1951, p. 288) the mineral from Zaaiplaats is in fact synchisite.

Table No. 7. - Analysis of bastnaesite

	1	Interpretation		2
		Fluorite	Bastnaesite	
Ce_2O_3	30.52	-	30.52	32.76
$(Sa,Di)_2O_3$+ Y_2O_3 group	37.20	-	37.20	39.93
F	9.31	3.33	5.98	6.42
CO_2(ignition loss)	21.98	-	21.98	23.59
H_2O-	nil	-	nil	nil
P_2O_5	nil	-	nil	nil
Rem. = CaO ?	4.91	4.91	-	-
	103.92	8.24	95.68	102.70
-F=O	3.92	1.40	2.52	2.70
Totals	100.00	6.84%	93.16%	100.00

1. Bastnaesite, Mutue Fides 422, Potgietersrus District, Transvaal. Analyst, C.J. Liebenberg, Division of Chemical Services, Pretoria. Analysed in 1944. Remains are considered as CaO derived from fluorite impurities in the analysed sample.
2. 1 corrected for fluorite and recalculated to 100.

B. FLUORITE

This mineral, as the bastnaesite, occurs as veinlets in tysonite. Microscopically it was found to be more abundant in and near bastnaesite than in tysonite. It appears to be younger than both bastnaesite and tysonite, and occasionally occurs as thin lamellae interbedded with bastnaesite along the basal cleavage planes of the latter (plate IV).

The colour of the fluorite varies from purplish to greenish and colourless. On account of its association this mineral was first thought to be an yttrian or cerian variety but the following properties indicate a normal fluorite: S.G. $^{22}_{4}$ = 3.17 ± .01.

n = 1.4351 (Na light at 23°C - Method of minimum deviation).

a_o = 5.4630 ± .0005 A at 25°C.

A spectrographic analysis reveals traces of Fe, Mg, Sr, Al, La, Y?, Ce, and Si. These impurities are, however, common in most fluorites.

C. HELLANDITE ?

A few minute grains, at places vein-like, of a brownish-red mineral were noticed in thin sections of the tysonite. The largest grain encountered in eight thin sections had a diameter of 0.1 mm. only, and an attempt to lift some of the grains from a thin section for refractive index determination or for X-ray investigation was unsuccessful. The identification is, therefore, only based on the colour, the anisotropic character, the absence of pleochroism, the biaxial (2V large) positive character of the grains, and on the mineral association. The refractive indices are slightly higher than those of tysonite.

Hellandite is a silicate chiefly of calcium, rare earths, aluminium, and iron and was originally reported from a pegmatite near Kragero in Norway (Winchell, 1951, p. 518). This mineral was also tentatively identified by Strauss (1954, p. 157) in the tin-bearing breccia lodes on Welgelegen 357, in the Zaaiplaats Tin Mining Area.

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to Prof. J. Willemse who kindly contributed the sample. Thanks are also due to the Division of Chemical Services for the analyses made by them.

TISONIET VAN MUTUE FIDES

Opsomming in Afrikaans

Die optiese eienskappe en chemiese samestelling van fluoseriet en tisoniet van verskeie vindplekke word bespreek en die gevolgtrekking gemaak dat fluoseriet en tisoniet wel twee aparte minerale is en nie dieselfde mineraalsoort soos sedert 1921 aanvaar is nie. Dit word voorgestel dat die naam tisoniet behou word vir die eenassige, negatiewe fluoried van hoofsaaklik serium en lantanum en dat fluoseriet gebruik word vir die eenassige, positiewe materiaal wat 'n oksiefluoried van die genoemde seldsame aardes is.

Tisoniet uit die tinafsettings van Mutue Fides 422 in die Distrik Potgietersrus, Transvaal, word vervolgens beskryf. Hierdie materiaal is eenassig, negatief met $n\varepsilon_D = 1.608 \pm .002$; $n\omega_D = 1.614 \pm .002$; $n\omega_D - n\varepsilon_D = .006$; $n\omega_F - n\omega_C = .011$, en S.G. $^{24}_{4} = 5.995 \pm .005$. Dit is polisinteties vertweeling met die eerste orde piramied $(10\bar{1}2)$ as komposisie- sowel as tweelingvlak en met $0001 \wedge 10\bar{1}2 = 45^\circ\ 36'$. Die eenheidselgrootte van hierdie mineraal is bereken as $a = 4.122 \pm .005$ A, $c = 7.304 \pm .005$ A en $c/a = 1.772$. 'n Chemiese analise word aangegee en vergelyk met die van tisoniet en fluoseriet van ander vindplekke. Die materiaal vanaf Mutue Fides is gedeeltelik verander na basnasiet en aardagtige materiaal wat moontlik 'n oksied of oksiefluoried van die seldsame aardes is. Die chemiese, fisiese en optiese eienskappe van hierdie basnasiet word vergelyk met die van die mineraal vanaf ander vindplekke.

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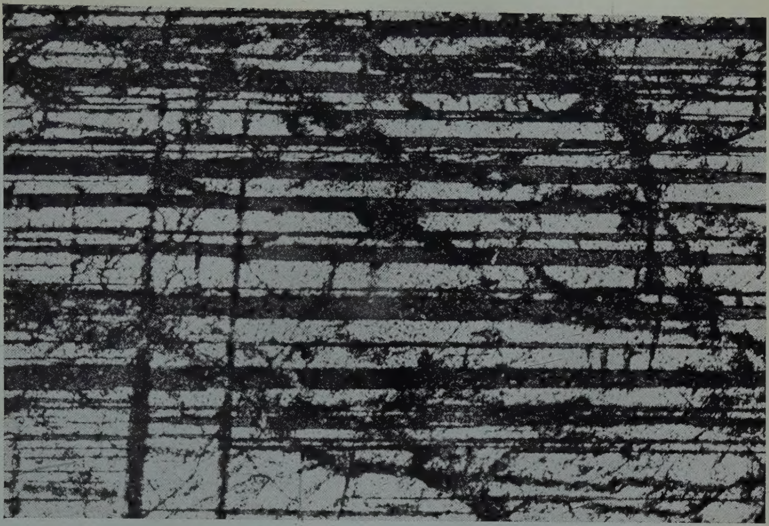

PLATE I.—Polysynthetic twinning in tysonite from Mutue Fides ($10\bar{1}2$ composition-plane—in this case two directions intersect almost at right angles). Crossed nicols, × 42.
Thin section No. 20048.

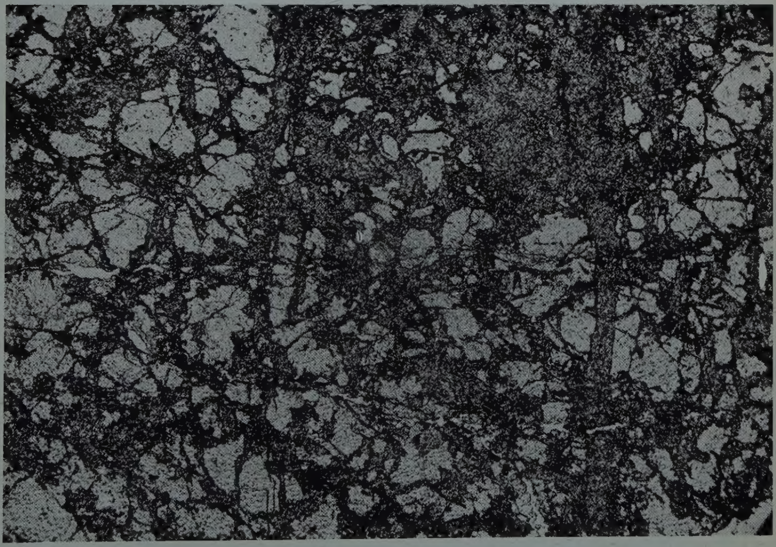

PLATE II.—Remnants of tysonite (light) in bastnaesite (dark).
Without nicols, × 42.
Thin section No. 20047.

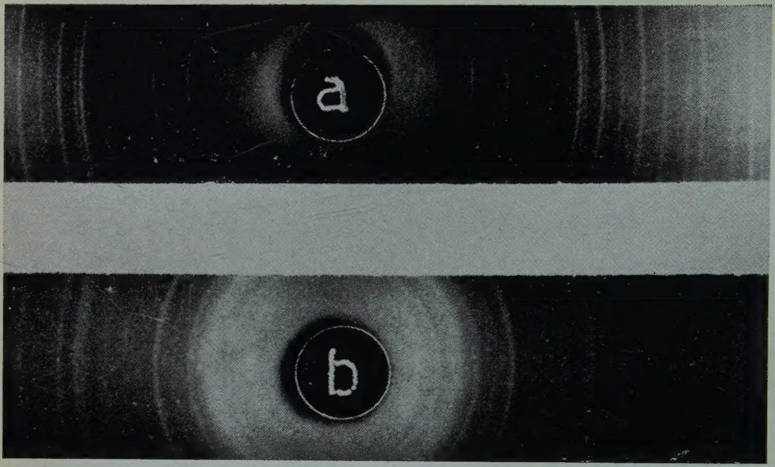

PLATE III.—X-ray diffraction patterns, front reflections only.
Co radiation. Camera radius = 57·3 mm.
a. Bastnaesite.
b. Earthy alteration product of tysonite, Mutue Fides.

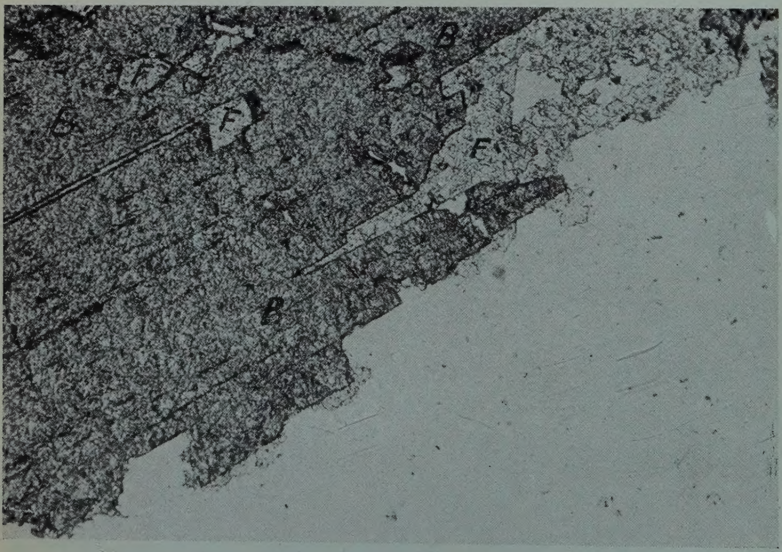

PLATE IV.—Fluorite (F) replacing bastnaesite (B), along the basal cleavage planes.
Without nicols, × 64.
Thin section No. 20048.

(PHOTO: S. A. Hiemstra.)